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Computer models as social learning tools in participatory integrated assessment

Joop de Kraker^{1*}, Carolien Kroeze¹ and Paul Kirschner²

¹ School of Science, Open University of the Netherlands, P.O. Box 2960, 6401 DL Heerlen, The Netherlands

² Centre for Learning Sciences and Technology (CELSTEC), Open University of the Netherlands, P.O. Box 2960, 6401 DL Heerlen, The Netherlands

Participatory integrated assessment (PIA) is a structured process conducted with stakeholders to assess the environmental, economic and social dimensions of a complex issue and the impacts of policy choices. PIA may result in social learning – a convergence in the stakeholders' perspectives on the problem and its solutions – which creates a basis for more sustainable, collective action. This paper addresses the role of computer models used in integrated assessment in supporting social learning and discusses a selection of model-based PIA projects. We argue that models may play two important roles. First, with models the consequences of options can be explored turning the PIA process into an experiential learning cycle for the stakeholders. Second, models provide a platform and structure for stakeholders to communicate, negotiate and integrate their perspectives. However, in many PIA projects, computer models fail to play a significant supporting role in social learning. Experiences with other participatory modelling approaches indicate that a higher degree of stakeholder involvement in model development can increase the effectiveness of models as social tools. This, however, is time- and resource-intensive and difficult to scale up but insights from collaborative learning science and technology may help to enhance the effectiveness and efficiency of PIA model in supporting social learning.

Keywords: computer models; participatory integrated assessment; participatory modelling; social learning

Introduction

Many of the major sustainability issues in environmental and resources management are presently defined as 'wicked' (Rittel and Webber, 1973) or 'unstructured' problems (Hisschemöller and Hoppe, 1995). Such problems are hard to manage, because they extend over multiple scales and dimensions, the environmental dimension being tightly interwoven with the social and economic dimensions. As a consequence, they are surrounded by structural uncertainties and involve many interdependent stakeholders with often diverging or even conflicting interests and perspectives on what the problem actually is as well as on possible ways to solve it. A typical example is the current issue of climate change. To produce knowledge relevant to the management of such complex problems, scientists need integrated approaches that include multiple types of expertise and multiple viewpoints. Integrated

assessment (IA) is a major example of such an approach (Harris, 2002). It is a structured process to assess the environmental, economic and social dimensions of a complex issue and the impacts of policy responses to it. IA explicitly aims to make these integrated insights available to decision makers, using knowledge from various disciplines and sources (Rotmans, 1998). Computer models allowing for the simulation and examination of complex and dynamic systems have traditionally been a major tool in IA for knowledge integration and quantitative explorations of trends and impacts (Rotmans, 1998). In IA of climate change, where the roots of IA lie, such models have even become the dominant means of scientific knowledge production. Over the past decades, the application of IA has spread outside the area of climate change to other issues such as transboundary air pollution

*Corresponding author. Email: joop.dekraker@ou.nl

(Amann *et al.*, 1999), water resources management (Pahl-Wostl, 2002), land use (Kok *et al.*, 2007) and, recently, agricultural sustainability (van Ittersum *et al.*, 2008).

Box 1 Definitions of terms

Integrated assessment (IA): a structured process to assess the environmental, economic and social dimensions of a complex issue and the impacts of policy responses to it. IA explicitly aims to make these integrated insights available to decision makers, using knowledge from various disciplines and sources.

Participatory integrated assessment (PIA): integrated assessment involving stakeholders, whereas the degree of involvement may range from low to high and may differ per assessment phase. The assessment is assumed to be computer-model-based and future oriented.

Stakeholders: individuals representing their own or their organization's interest in the problem to be assessed. Stakeholders may include government officials or other decision makers, but scientists conducting the assessment are not included. This is not because they may not have any stake in the issue, but because they perform a different role in the PIA process.

Decision makers: those with any degree of formal decision power over the system on which the assessment focuses. Depending on the type of system (public or private), synonyms used are policy makers, administrators, managers.

Options: possible ways to solve the problem. Depending on the type of problem, synonyms used are possible solutions, policy options, policies, choices, decision alternatives, alternative (management) strategies.

Recommendations: insights representing the outcome of the assessment for decision makers. Often the focus is on the preferred way to solve the problem, e.g. a set of selected policy options or management strategies. Includes action or management plans, policy advice. It may also take the form of a recommended design of a policy or management experiment.

Computer model: formal, quantitative models, representing a system with a set of mathematical equations. The term does include various forms of quantitative models, such as process-oriented simulation models and goal-oriented optimization models, but does not refer to qualitative, graphical models, which may also be computer-based. Also includes system model, IA model, integrated model and dynamic model.

Social learning: a process of convergent change in the stakeholders' perspectives on the problem, possible solutions and risks, as well as their own and the other stakeholders' position with regard to solving the problem.

After about a decade of IA research and development, major proponents of this approach have come to the conclusion that the impact of IA on decision making had been fairly limited (Rotmans, 2006). To improve its contribution, IA is increasingly being conducted in close interaction with policy makers and societal stakeholders. Such a participatory approach may (1) improve the quality of the assessment by including relevant non-scientific sources of knowledge and experience, (2) enhance its relevance, legitimacy and credibility by accounting for the diversity in perspectives on the problem and possible solutions among the stakeholders, and thus (3) increase the basis of support for the outcomes of the assessment (Hisschemöller *et al.*, 2001; Klopogge and van der Sluijs, 2006). An aspect of participatory integrated assessment (PIA) that has recently received considerable attention is social learning of stakeholders, that is, a process of reframing and convergence of their perspectives on the problem and possible solutions. From the perspective of sustainable development, social learning is a desirable outcome, as it creates the basis for integrated solutions that require collective support and concerted action of multiple stakeholders (Röling, 2002). This raises the question as to whether and how computer models that have such a central place in IA can function as tools to stimulate and support social learning among stakeholders. This paper addresses the various support roles that computer models may have in social learning in IAs. To this end, we discuss a selection of model-based PIA projects. In Box 1, the set of terms used in this paper are defined and synonyms found in the source publications are given.

Learning in PIA

Stakeholder participation in PIA takes many different forms. A common way of classifying PIA projects is according to the degree of stakeholder involvement in terms of decision-making authority, inspired by Arnstein's famous 'ladder of citizen participation' (Arnstein, 1969). Volkery *et al.* (2008) translated the five rungs of this ladder to the PIA context as informing, consulting, co-designing, co-deciding and stakeholders deciding. In PIA, decision making concerns the design of the process as well as which knowledge is included in the products. The lowest degree of participation, scientists informing stakeholders, represents a situation in which scientists are completely in control of the process and only include scientific

knowledge. The next rung on the ladder, scientists consulting stakeholders, represents a situation in which stakeholders provide input upon request, but scientists decide whether and how to use it. Co-designing, or co-producing, represents probably the most common interpretation of stakeholder participation in IA. Stakeholders are actively involved and contribute to the process or the product, but the scientists remain responsible. At the two highest rungs of the participation ladder, stakeholders are partially or fully in charge of the design of the process and the products. The latter situation is unlikely however in the case of PIA, which is typically initiated by scientists.

The various degrees of stakeholder participation in PIA can also be characterized in terms of knowledge exchange (Hage and Leroy, 2007), ranging from a unidirectional flow from scientists to stakeholders (informing) or from stakeholders to scientists (consulting), to a process of mutual exchange (co-producing, co-deciding, stakeholders in charge). Likewise, the dominant type of learning interaction in the PIA process also differs with the rungs of the participation ladder. Learning interactions range from stakeholders learning from scientists (informing) or vice versa (consulting), mutual or co-learning of scientists and stakeholders (co-producing), to scientists mainly supporting mutual learning among stakeholders (co-deciding, stakeholders deciding) (van de Kerkhof, 2006; Bohunovsky and Jäger, 2008; Tuinstra *et al.*, 2008). When learning concerns acquiring new technical knowledge and insights on, for example, effective policy instruments or important constraints, we speak of instrumental or 'single-loop' learning. Learning may also concern the underlying assumptions, norms and goals that determine how participants frame and define the problem. When the interactions in a PIA project result not only in a change in instrumental knowledge, but also in a change in the participants' perspective on the problem and consequently the possible solutions, we speak of reframing or 'double-loop' learning. Some authors distinguish a third order of learning, transformative or 'triple-loop' learning, when the deeply held beliefs and core values of participants change (e.g. Keen *et al.*, 2005; Pahl-Wostl, 2009). More often however, changes in beliefs, values, norms and goals are taken together as 'double-loop' learning, with the implicit assumption that people's core values and beliefs are quite stable and unlikely to change in the context of a PIA (cf. Sabatier, 1988). The concepts of single- and double-loop learning

were coined by Argyris and Schön (1978) and refer to the feedback loops in a learning process. In single-loop learning there is only one loop of error correction, that is, between actions and their outcomes. Actions are changed when they do not have the desired outcomes, without questioning or altering the existing framework of objectives and causal beliefs underlying the actions. In double-loop learning, a second feedback loop is added when the perceived range of options does not result in desired outcomes. In this feedback loop, the underlying frame of values, objectives, norms and beliefs is included in the learning process. In cases where double-loop learning takes place among the participants of a PIA, their individual perspectives might not only change, but this change might be convergent in the sense that the perspectives become (more) similar and overlapping as a result of the interactions in the group. In the literature on sustainable environmental and resource management (e.g. Leeuwis and Pyburn, 2002; Keen *et al.*, 2005; Wals, 2007) and IA (Tuinstra *et al.*, 2008), this phenomenon is commonly referred to as 'social learning'.

The concept of social learning is interpreted and applied in diverse ways. For example, 'change' may include not only cognitive change, but also change in behaviour and institutional arrangements and the 'group' at stake may include multiple stakeholders or peers (Leeuwis *et al.*, 2002). In the context of PIA, we consider social learning as a process of social-cognitive and social-relational change in a diverse group of stakeholders supported by scientists. In the social-cognitive dimension, there is a convergent change in the stakeholders' perspectives on the problem, possible solutions and risks as well as their own and the other stakeholders' position and responsibility with regard to solving the problem (Leeuwis, 2002). Change in the social-relational dimension involves the development of social capital, such as trust, improved communication and better working relations (Pahl-Wostl and Hare, 2004). In PIA, the substantive outcome of social learning will be a collectively supported decision, strategy or policy advice. As for IA, this is the end-product. It is hoped, of course, that this may be followed by a sequence of other, even more substantive outcomes, such as changes in stakeholder behaviour at individual and institutional level, concerted or collective implementation of planned actions (including changes in institutional arrangements), and better, more sustainable environmental and resources

management. Muro and Jeffrey (2008) conducted a critical review of claims and outcomes of social learning and listed many factors fostering social learning, such as stakeholder selection (Prell *et al.*, 2006; Cuppen *et al.*, 2010). This paper concentrates on the supporting role of models in social learning. The following sections discuss whether and how the computer models typically used in IA can serve as tools for social learning, with a focus on the social–cognitive dimension.

Computer models as social learning tools

Computer models allowing for the simulation and examination of complex and dynamic systems are major tools in IA (Rotmans, 1998; see Lotze-Campen (2007) for an extensive overview of IA models). In IA such models mainly serve to (1) integrate knowledge from a variety of scientific disciplines and sources and provide a common, interdisciplinary understanding of complex environmental problems, (2) analyse the causes and impacts of these problems across multiple scales of time and space, and (3) explore and assess policy and management options and their trade-offs (Siebenhüner and Barth, 2005). A model-based IA may broadly be divided into a pre-modelling phase, a modelling phase and a post-modelling phase (Ewert *et al.*, 2009), although these phases are not at all strictly separated, as many PIA projects follow an iterative and cyclic process. During each phase and step, the role of stakeholders in PIA may range from passively providing inputs when asked for or actively bringing in their knowledge and perspectives, to having full responsibility for a step, such as scenario development (Volkery *et al.*, 2008). The pre-modelling phase ideally results in clear specifications of the structure and functionalities of the quantitative computer model to be developed in the next phase. This requires the steps of problem description, system description, scenario development and formulation of options. In the modelling phase, the system as defined in the previous phase is examined quantitatively. The aim is to gain a better understanding of the system's behaviour, in particular how it responds to the external drivers defined in the scenarios and to the selected range of options. The qualitative descriptions of the system, scenarios and options must therefore be translated into a quantitative computer model and input data. The post-modelling phase deals with the outcomes of the modelling phase and includes

three major steps: visualization of model results, evaluation of options and formulation of recommendations. Frequent iterations between the evaluation step and the steps in the pre-modelling phase represent the essence of the assessment procedure and provide the crucial feedback link between choices and consequences. With this feedback link, the PIA process resembles Kolb's experiential learning cycle (Kolb, 1984). In this cycle, the learner moves from experiencing the effects of actions to reflecting on these effects, from reflecting to (re)conceptualizing the relation between actions and effects and generalizing these to theory. The learner may then decide on new actions based on the adapted theory, and the experiences that follow from these actions start another learning cycle. Social learning has been defined as an interactive process of shared, experiential learning, amplified by facilitated communication and dialogue (Jiggins *et al.*, 2007). From this perspective, the major support functions of models in social learning in PIA can be summarized as follows. First, models help to close the learning cycle by supporting the essential feedback loop from actions through (simulated) experience and reflection to reconceptualization. Second, models as external representations of the problem (and the system) can help to support communication and dialogue among stakeholders to make it an interactive, shared learning process.

Social learning in model-based PIA projects

In the literature on PIA and related approaches employing a participatory modelling approach, frequent references can be found to the role of computer models as tools to support stakeholder learning, communication, discussion, negotiation or consensus-building. Explicit analyses of the role of these models in supporting social learning are rare, however, and evidence of learning outcomes is hardly ever presented to support conclusions that learning had taken place, other than self-reported learning. Our discussion about model-based support of social learning in the reviewed cases below is therefore mainly based on our own interpretation of the published information. The cases are selected through a search of the published literature on the grounds of being integrative and future-oriented in scope, participatory by involving a diversity of stakeholders, and focused on more sustainable environmental and

resource management strategies and policies, using computer-model-based assessments. The main features of the nine selected model-based PIA projects are summarized in Table 1. The cases are presented below in chronological order.

Rains

The ‘regional air pollution information and simulation’ (RAINS) model has already been used since the 1980s to support international negotiations under the convention on long-range transboundary air

pollution in Europe (Amann *et al.*, 1999). The stakeholders in this case are delegates from various countries, using the model to learn about relevant emission reduction targets and cost-effective strategies to reach these targets (Tuinstra *et al.*, 1999). In the early 1990s, a number of novel concepts were introduced into the negotiations separately from the model, such as the ‘critical load’ concept, which did lead to a collective reframing of the perspectives of delegates and a breakthrough in the negotiations (Siebenhüner, 2002). The RAINS model was adapted to

Table 1 | **Main features of nine model-based PIA projects. See text for a detailed discussion of cases and references**

Project	Area	Objective	Stakeholders	Intended model use
RAINS	Transboundary air pollution	Support international negotiations	Delegates from European countries	Identification of cost-effective emission reduction strategies
Delft process	Climate change	Support preparations for Kyoto negotiations	Policy makers from European and developing countries	Assessment of long-term impacts of climate policy measures
ULYSSES	Climate change	Inform regional policy making with citizen assessment	Citizen focus groups	Explanation of the problem and exploration of regional mitigation options
QUEST	Regional development	Stimulate development of long-term, sustainable policy at regional level	Local government policy makers and technical staff; community members	Definition of ‘desirable futures’ in long-term goals and exploration of consequences
VISIONS (Green Heart case)	Regional development, land use	Inform spatial planning policy with integrated scenarios	Representatives from research, policy, business and NGO sectors; inhabitants	Underpinning/visualizing storylines with quantitative, spatially explicit simulations
HarmoniCOP (Flemish case)	Water resources management	Develop new river basin management strategy	‘Interested parties’: e.g. administrators, farmers, environmentalists	Assessment of strategies concerning flooding hazards and ecological impacts
ATEAM	Ecosystem management	Inform policy with assessment of vulnerability of European ecosystems to global change	Policy advisors and sectoral representatives (e.g. tourism, forestry, agriculture, nature conservation)	Quantify and map impacts of global change on provision of ecosystem services
PRELUDE	Land use	Engage policy makers in discussion about long-term developments and response strategies	Policy makers, researchers, representatives of interest groups, independent thinkers	Underpinning/visualizing storylines with quantitative, spatially explicit simulations
Sustainable uplands	Ecosystem management	Develop choice of options for sustainable rural development	Local policy makers, land managers, water companies, environmentalists, recreational groups	Visualizing scenarios and assessment of options with quantitative, spatially explicit simulations

support the operationalization of these new concepts with calculations. As such, the model did not function as a social learning tool, but more as an instrumental learning tool.

Delft process

In the Delft Process, the 'Integrated Model to Assess the Global Environment' (IMAGE) model for climate change assessment (Bouwman *et al.*, 2006) was used to support policy makers from European and developing countries in their preparations for the negotiations leading up to the Kyoto protocol (van Daalen *et al.*, 1996). Initially, there appeared to be a mismatch between the long-term orientation of the IMAGE model and the focus on short-term policy decisions of the participants. A breakthrough and collective reframing was achieved with the introduction of the 'safe landing' concept, which tracks long-term climate goals back to present needs for policy measures. This re-orientation made the model relevant to the participants, who then used it to learn more about the various impacts associated with long-term goals in climate policy (Stalpers *et al.*, 2009). In the Delft process, the IMAGE model thus mainly served for single-loop learning, although it may have played a role in stimulating discussions and perhaps social learning on the value-laden assumptions behind the criteria for a 'safe landing' in terms of critical impact indicator values.

ULYSSES

The 'Urban Lifestyles, Sustainability and Integrated Environmental Assessment' (ULYSSES) project pioneered PIA with heterogeneous focus groups of citizens. These groups met for five sessions to debate climate change and to produce a citizen assessment report on regional impacts, policy goals and options for mitigation (Kasemir *et al.*, 2000). The process was facilitated by a group moderator and a model moderator, assisting in the use of different computer models to support the debate. These models ranged from complex global models to simple accounting tools (Dahinden *et al.*, 2000). Analyses of the role of the computer models suggest that the models were successful at conveying the temporal and spatial scale of climate change, the complexity of the system and the uncertainties in our understanding of it. However, most participants felt that the computer models were less instrumental for the exploration of policy options. This was caused by a range of factors, such as insufficient user-friendliness, lack of transparency and considerable complexity of the

models, which usually made direct interaction impossible. Another reason was that the models could not support the type of assessments the participants were most interested in, that is, with a spatial focus on their own region, a time horizon of 10–20 years and assessment of feasibility of options rather than just effectiveness (Dahinden *et al.*, 2000). An exception was the personal CO₂ calculator, a simple tool to relate CO₂ emissions to lifestyle choices produced at the request of participants in the Swiss case study (Schlumpf *et al.*, 1999). It proved a good tool to support discussions, but these were primarily focused on options to cut personal CO₂ emissions. With Siebenhüner and Barth (2005), we conclude that model-supported learning in ULYSSES concerned primarily single-loop learning about the problem and personal options to contribute to a solution. Given the problematic interaction with the computer models and the short time frame of the focus group workshops, significant changes in individual values seem unlikely. Moreover, although the model interaction did stimulate the debate around issues of ethical values and causal beliefs, 'it is also possible that such a productive discussion would have taken place simply by bringing the topic to the table with some overheads or by talking' (Dahinden *et al.*, 2000).

QUEST

QUEST is an interactive computer simulation tool to set long-term goals for sustainable regional development and explore the consequences of these 'desirable futures' (Carmichael *et al.*, 2004). It was used in the Georgia Basin Futures Project in Canada, which aimed explicitly to stimulate dialogue and social learning on 'what sustainability means in concrete terms for a given context' (Robinson, 2003). The PIA part of the project consisted of half-day workshops in three municipalities with local policy makers, technical government staff and interested members of the community. Interaction with QUEST appeared to result in double-loop learning of individual participants, developing a more holistic view of sustainability (Shapka *et al.*, 2008). In the workshops, after QUEST was shut down, stakeholders had lively discussions on questions of implementation and proposed action (Robinson *et al.*, 2006). In this way, QUEST may stimulate social learning, but whether this actually occurred was not evaluated and seems unlikely, given that no collective outcomes were requested and given the very short duration of the interaction. This allowed

only one or two iterations between choices and consequences with QUEST and no feedback from discussions on proposed actions to the definition of 'desirable futures' in QUEST. Interaction with QUEST was further hampered by mismatches between the expectations of the stakeholders and what the model could deliver in terms of spatial resolution (local vs. regional) and function (planning tool vs. visioning tool).

VISIONS

The 'Integrated visions for a sustainable Europe' (VISIONS) project was one of the first in developing and testing a participatory methodology for developing scenarios for IA studies. In the project, integrated scenarios for sustainable development pathways were developed for Europe as a whole and for three specific regions in Europe in a dialogue between scientists and a range of stakeholders (Rotmans *et al.*, 2000). Computer models were used to underpin the scenarios quantitatively. For example, for the 'Green Heart' case (the Netherlands), a spatially explicit simulation model was developed, based on indicators selected by the stakeholders, to explore dynamic spatial trends and patterns associated with the storylines. The outcomes were discussed with the stakeholders in the next workshop (Rotmans *et al.*, 2000). Stakeholder learning related to the computer models remained single-loop in this project, since the participants learned about the implications of scenarios and causal connections, but a thorough reflection process that included changes in perspective was not reported by the project team (Siebenhüner and Barth, 2005). A reason for this may have been the focus of stakeholders on intangible issues, such as cultural identity, quality of life, social cohesion and institutional changes, which could not be captured in the quantitative computer models (Rotmans *et al.*, 2000). In the MedAction project, an IA of policies to combat desertification in the northern Mediterranean, the scenarios and methodology of the VISIONS project were further developed and adapted. Social learning was adopted as an explicit objective of the participatory scenario development and backcasting workshops with local stakeholders (Patel *et al.*, 2007). However, computer models did not play a role in this process, partly because of technical difficulties in translating qualitative storylines into quantitative model input (Kok and van Delden, 2009), and partly because it was feared that model-based quantification would hamper social learning

by creating a false sense of certainty and objectivity (Patel *et al.*, 2007).

HarmoniCOP

The 'Harmonising Collaborative Planning' (HarmoniCOP) project was one of the many European research projects that accompanied the introduction of the European Water Framework Directive (2000/60/EC), which emphasizes 'the involvement of all interested parties' in the development of river basin management plans. The project investigated the importance of social learning and the supporting role of information and communication tools (IC tools) in case studies on participatory water management in nine European countries (Pahl-Wostl *et al.*, 2007). In the final analysis of the HarmoniCOP case studies, IC tools were not included in the list of 26 key factors fostering social learning, but were listed as a (minor) barrier, mainly due to their complexity, which tends to exclude lay stakeholders (Mostert *et al.*, 2007). In one of the cases, a Flemish river valley development initiative, the IC tools included computer models (Maurel *et al.*, 2007). These models were developed in the course of the project to evaluate a range of scenarios with respect to flooding hazards and ecological impacts. However, the scientists were not willing to involve the stakeholders in their model-based search for alternative scenarios, because the model outcomes were highly uncertain and contested and did not confirm optimistic expectations concerning win-win solutions. The models, therefore, did not play a supporting role in social learning in this case.

ATEAM

The overarching goal of the 'Advanced Terrestrial Ecosystem Assessment and Modelling' (ATEAM) project was to produce an IA of vulnerability of European ecosystem functions to global change (Schröter *et al.*, 2005). A stakeholder dialogue was embedded in the research process, with three general and three sectoral workshops, during which scientists presented scenarios, modelling approaches, model outcomes and conclusions on vulnerability for a range of sectors. The focus of the participatory process was threefold: to prompt critical feedback, to satisfy specific data needs for better model developments and to develop best dissemination strategies for the model outputs. Therefore, the degree of stakeholder participation in the ATEAM dialogue can best be described as a combination of informing and consulting stakeholders (de la Vega-Leinert *et al.*, 2008). The

discussions in the workshops focused on technical issues rather than the underlying perspectives and on stakeholder–scientist interaction rather than interaction among stakeholders, and therefore social learning is an unlikely outcome of this dialogue. Mutual learning between stakeholders and scientists was probably primarily single-loop, as the role of stakeholders was framed as providers of data and the space left for manoeuvre by scientists in addressing stakeholder feedback was rather marginal (de la Vega-Leinert *et al.*, 2008).

PRELUDE

In the ‘Prospective environmental analysis of land-use development in Europe’ (PRELUDE) project, the European Environmental Agency (EEA) recruited a group of about 30 stakeholders and experts to develop long-term alternative scenarios for land use in Europe (Volkery *et al.*, 2008). The aim was to develop compelling scenario storylines to engage policy makers in ‘strategic conversations’, discussions about future developments and response strategies. Stakeholders were given full responsibility for identifying major driving forces and developing the scenario storylines, while experts took a supporting position and underpinned the storylines with the help of land-use simulation models. Storyline development and quantitative modelling of land-use changes were refined in an iterative process in three consecutive stakeholder workshops. The EEA found the final scenarios to be quite useful in outreach workshops for policy makers and high-level stakeholders. No formal evaluation of learning was conducted, but the outcomes suggest that the process of scenario development resulted in social learning among the stakeholders. A very heterogeneous group of stakeholders managed to formulate five very different yet consistent and interesting scenario storylines, and developed a strong trust in the validity and suitability of their problem analysis and the scenarios. The project was thus successful in bridging gaps and improving communication and collaboration between quite different stakeholders. Although quantitative modelling was important for ensuring consistency in the scenarios and for visualizing the developments with maps and graphs, it appears that it did not contribute to the social learning of stakeholders. Possible reasons are the limited opportunity for feedback between stakeholders and modellers (there was only one round of iteration from stakeholder outputs to modelling and back), and the focus of modellers on the scientific credibility of the

exercise rather than its participatory and exploratory value (Volkery *et al.*, 2008).

Sustainable uplands

The aim of this ongoing project is to combine knowledge from local stakeholders, policy makers and scientists to develop a choice of options to sustainably manage future rural change in UK uplands (Hubacek and Reed, 2009). For the study site where it is most advanced, the Peak District National Park, the project is currently in the modelling phase. Stakeholders (e.g. land managers, water companies, recreational groups, environmentalists and local policy makers) were involved through interviews and site visits in the scoping of the problem, defining the system boundaries, identifying major drivers, setting of goals and selection of sustainability indicators. Researchers produced a conceptual model (cognitive map) of the system, based on a literature review and interviews with stakeholders, and further refined this model after discussing it in a multi-stakeholder workshop. The result represented a wide variety of stakeholder knowledge and perceptions. As the conceptual model of the entire system had become highly complex, the researchers produced simpler sub-models as tools to communicate future scenarios and as starting points for group discussions. The project is designed as a social learning cycle, so the next steps are to translate the conceptual model into an integrated socio-economic and biophysical computer model, to quantify the scenarios in a spatially explicit manner, discuss the outcomes with stakeholders, identify and evaluate promising land management strategies, and formulate policy recommendations that are supported by the various stakeholder groups (Dougill *et al.*, 2006). Although the project explicitly aims at social learning, this process has not been evaluated thus far. The integrated model will supposedly play a key role in the social learning process by allowing joint assessment of options and a feedback loop from options to goals. However, at the current stage modelling appears to have hampered social learning rather than supported it. The conceptual model, which could serve as a platform for negotiation and integration of different perspectives, was preliminarily developed by researchers and was too complex to communicate and discuss with the stakeholders. Furthermore, translating this conceptual model into an integrated computer model turned out to be technically very challenging and time-consuming. As a consequence, continuity in stakeholder participation is difficult to

maintain, which also hinders social learning (Prell *et al.*, 2007).

Discussion

A number of model-based PIA projects were presented and discussed as to whether and how the models supported social learning. Our analysis showed that computer models used in PIA can support social learning of stakeholders in two major ways. First of all, the model provides the link between choices and consequences that can turn the PIA process into an experiential, double-loop learning cycle when reflection on model outcomes is fed back to the problem definition stage. Second, the model provides a platform and structure for the stakeholders to communicate, negotiate and integrate their views. However, in the cases of model-based PIA that we reviewed, computer models often failed to play a significant supporting role in social learning. Concerning the first way of supporting social learning, we argue that a direct feedback loop from the assessment of model outcomes to the definition of the problem was rarely successfully established. There are several reasons for this. A major obstacle was that stakeholders often did not accept the model as a relevant representation of the problem and the system, because the spatial or temporal scale chosen for the model or the variables and indicators included did not match the interests and focus of the stakeholders. In the case of ULYSSES and VISIONS, the model could not be adapted and hence did not play a significant role. In the case of RAINS and the Delft process, the model became relevant and was used for instrumental learning only after a new 'bridging' concept was introduced in the dialogue. In these two cases, it can be argued however that the models did function as social learning tools in an indirect way by providing the means to operationalize the bridging concepts and giving these concepts the necessary scientific credibility. Another reason for the lack of a feedback loop in the presented cases was that the process design did not always allow sufficient time to establish this loop (QUEST, PRELUDE) or did not foresee such a feedback loop at all (ATEAM). Concerning the second major way in which models can support social learning, we argue that in these cases the models were used only in a very limited way as a platform for communication, negotiation and integration of a diversity of stakeholder perspectives. This was sometimes due to insufficient

user-friendliness and model complexity (ULYSSES, HarmoniCOP), but a more important reason was the inflexibility of the models. Either the structure of the model predetermined by the modellers and stakeholders could only influence the options to be assessed with the model (Delft process, ULYSSES), or the models could not represent the type of issues the stakeholders were interested in (VISIONS, PRELUDE). Attempts to use existing integrated land-use models to support farmer learning at the strategic level in tropical and western agriculture have yielded similar experiences (van Paassen, 2004; Sterk, 2007).

The cases we discussed are more or less typical PIA projects, combining a broad, integrated, model-based assessment with a long-term outlook on the issue and its possible solutions. As such they represent a specific type of participatory modelling (Bots and van Daalen, 2008), and are related to other approaches in participatory modelling with a more narrow focus and/or more short-term orientation. In two of these approaches, mediated modelling (van den Belt, 2004) and companion modelling (Bousquet and Trébuil, 2005), computer models appear to be much more effective in supporting social learning than in model-based PIA. This is not surprising, as consensus-building and collective learning are explicit goals in these approaches. In both approaches, stakeholders are involved in model development from the start, through graphical interfaces or role-playing games. Stakeholders can bring in their views either by building the model together or through modellers working with highly flexible models. Frequent iterations, collective reflection on model outcomes and feedback to the definition of the problem and the range of possible solutions are important elements in both approaches. The advantage of this highly participatory approach is that the computer models used to assess options will generally be accepted by the stakeholders as salient (relevant to their concerns), legitimate (reflecting their values and interests) and credible (in accordance with their causal beliefs) (Cash *et al.*, 2003; Stalpers *et al.*, 2009). A drawback is that the approach is very time-consuming and resource-intensive. Even with companion modelling, focusing on local communities and well-defined problems, it takes several years to complete the whole process. Scaling-up is therefore problematic (Lynam *et al.*, 2002; Barnaud *et al.*, 2007), as is demonstrated by the case of the UK Sustainable Uplands project.

A more intensive participatory modelling approach similar to mediated or companion modelling may thus

increase the effectiveness of computer models in supporting social learning, but to be feasible it must be made more efficient, given the complexity of issues and models in PIA and the usual limitations in time and resources. A number of recent developments suggest that there is scope for more efficiency in two major aspects. One aspect is the time-consuming integration of stakeholder perspectives into the complex computer models used in PIA. This is even more problematic when no consensus is reached or sought in the pre-modelling phase to prevent premature closure (van de Kerkhof, 2006), and multiple model versions are needed to represent the plurality in stakeholder views. To make the translation from stakeholder perspectives to computer models more efficient, use could be made of novel graphical, semi-quantitative modelling tools such as fuzzy cognitive mapping (van Vliet *et al.*, 2010) and qualitative probabilistic networks (van Kouwen *et al.*, 2008), linking conceptual models effectively with simulation models. In addition or alternatively, computer models could be made more flexible, for example by anticipating stakeholder value diversity in so-called pluralistic models (van Asselt and Rotmans, 2001) or models that allow for different problem and goal definitions (Groot *et al.*, 2007), or by using a component-based modelling framework (Ewert *et al.*, 2009). Another aspect is the limited time that is usually available for interaction between the stakeholders and the model, often severely restricting the number of iterations and loops in the learning cycle. A range of novel tools are currently available to make the stakeholder–model interaction more efficient. Examples are three-dimensional visualization of simulated land-use changes in landscapes (Griffon *et al.*, 2010), tools to scan interactively model outcomes (Verweij *et al.*, 2006), interfacing of participants and the computer model through role-playing games in a face-to-face setting (Valkering *et al.*, 2008) or as a multi-player virtual reality game

(Wien *et al.*, 2003), or integrating the model in a web-based virtual learning environment, which can be accessed from home (cf. Milrad *et al.*, 2005).

Summarizing, there appear to be many options to make IA computer models more effective and efficient as social learning tools. However, critical evaluations of these options have not been conducted so far and no validated guidelines are available on how to design and combine IA computer models with other tools to effectively and efficiently support the social learning of stakeholders. This requires in-depth studies of the interaction between modelling tools and social learning processes in PIA. Up to now, evaluations of learning tools in IA have been characterized by limited attention to social–cognitive processes and are informed by only a small selection of learning theories (cf. Maurel *et al.*, 2007). We suggest that such studies could greatly benefit from the theories and methods from the fields of group cognition and collaborative learning (O'Donnell *et al.*, 2006; Akkerman *et al.*, 2007), and in particular from the rapidly expanding area of computer-supported collaborative learning (CSCL) (Kirschner *et al.*, 2003; Strijbos *et al.*, 2004; Stahl, 2006). An example of a relevant CSCL study is the work of Beers and colleagues on tools to facilitate the negotiation of common ground in a heterogeneous group (Beers *et al.*, 2006; Kirschner *et al.*, 2008). In participatory modelling (e.g. Vennix, 1999), such negotiation is implicitly required but not supported. The study of Beers shows how the insights and methods from CSCL are helpful in analysing the learning process, designing learning support tools and evaluating their effectiveness. It is our expectation, therefore, that connecting the fields of PIA and collaborative learning science and technology will significantly advance our understanding of how computer models can support social learning for more sustainable environmental and natural resources management.

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